

PREPARATION OF THE FUTURE EUROPEAN LAUNCH VEHICLES

RE-ENTRY

OPERATIONAL LAUNCHERS

European Directions for Hypersonic Thermal Protection Systems and Hot Structures

31st Annual Conference on Composites Materials and Structures
Daytona Beach, FL
January 22, 2007

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REUSABILITY

Agenda



◆ **Background**

- Comments on prior ESA workshop
- X-38
- Hopper

◆ **Flight Vehicle Based Technology Development**

- IXV (ESA)
- EXPERT (ESA)
- USV (Italy)
- SHEFEX (Germany)
- SHyFE (UK)
- LEA (France)
- Foton (Russia)

◆ **Non-Vehicle Specific Technology**

◆ **Concluding Remarks**

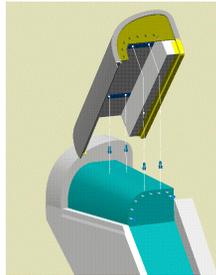
European TPS and Hot Structures Research and Development

- ◆ **TPS and hot structures research and development critical for future space vehicles**
- ◆ **Developing next generation TPS and hot structures technology (not Space Shuttle derived technology)**
- ◆ **Long-term funding based on technology needs**
- ◆ **Wide industry support and commitment to X-38 program**
- ◆ **Test facilities developed for TPS and hot structures development**
 - Thermal/structural test chamber
 - Arc-jet tunnels developed in recent years
- ◆ **Technology development has broad base**
 - Fabrication
 - Testing
 - Large components
 - Fasteners
 - Bearings
 - Oxidation protection
 - Damage repair
 - Life cycle

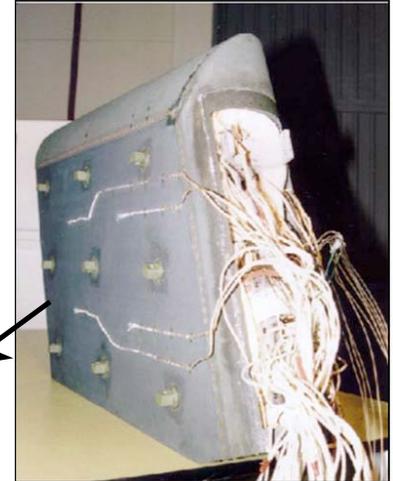
European TPS and Hot Structures Research and Development

- ◆ **Proposing numerous experimental launch vehicles dedicated to or with TPS and hot structures research of prime consideration**
- ◆ **Committing significant resources to the development of TPS and hot structures for future space vehicles**
 - \$20 million spent on C/SiC body flaps for X-38, \$50M on X-38 technology by Germany
 - Many companies involved (committing resources) in developing C/SiC hot structure for X-38
 - Large thermal/structural test chamber developed specifically for verification of X-38 hot structure
- ◆ **European TPS & Hot Structures Emphasis**
 - Developing ceramic matrix composite and metallic TPS with fibrous insulation
 - Waterproofing not required
 - Larger unit size (reduce part count)
 - More durable (reduced inspection and repairs)
 - Developing ceramic matrix composite and metallic hot structure
 - No ceramic tile development
 - Limited development with blanket insulation

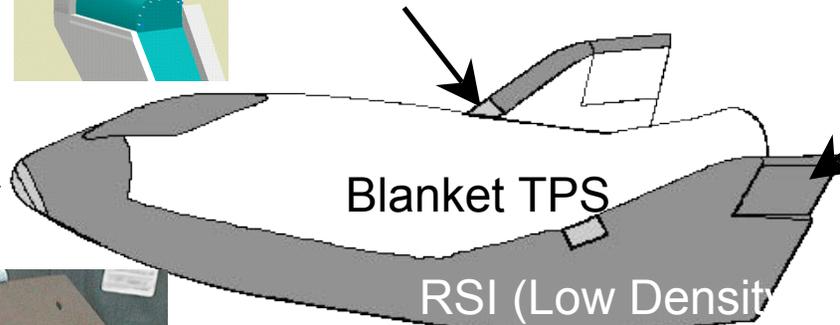
X-38 Hot Structures



- ◆ **C/SiC leading edge**
(flight experiment, 2000°F)
 - MT Aerospace (Germany)



- ◆ **Metallic rudder**
(Dutch Space)



- ◆ **C/SiC nosecap & skirts, $T_{max} \sim 3200^{\circ}F$**

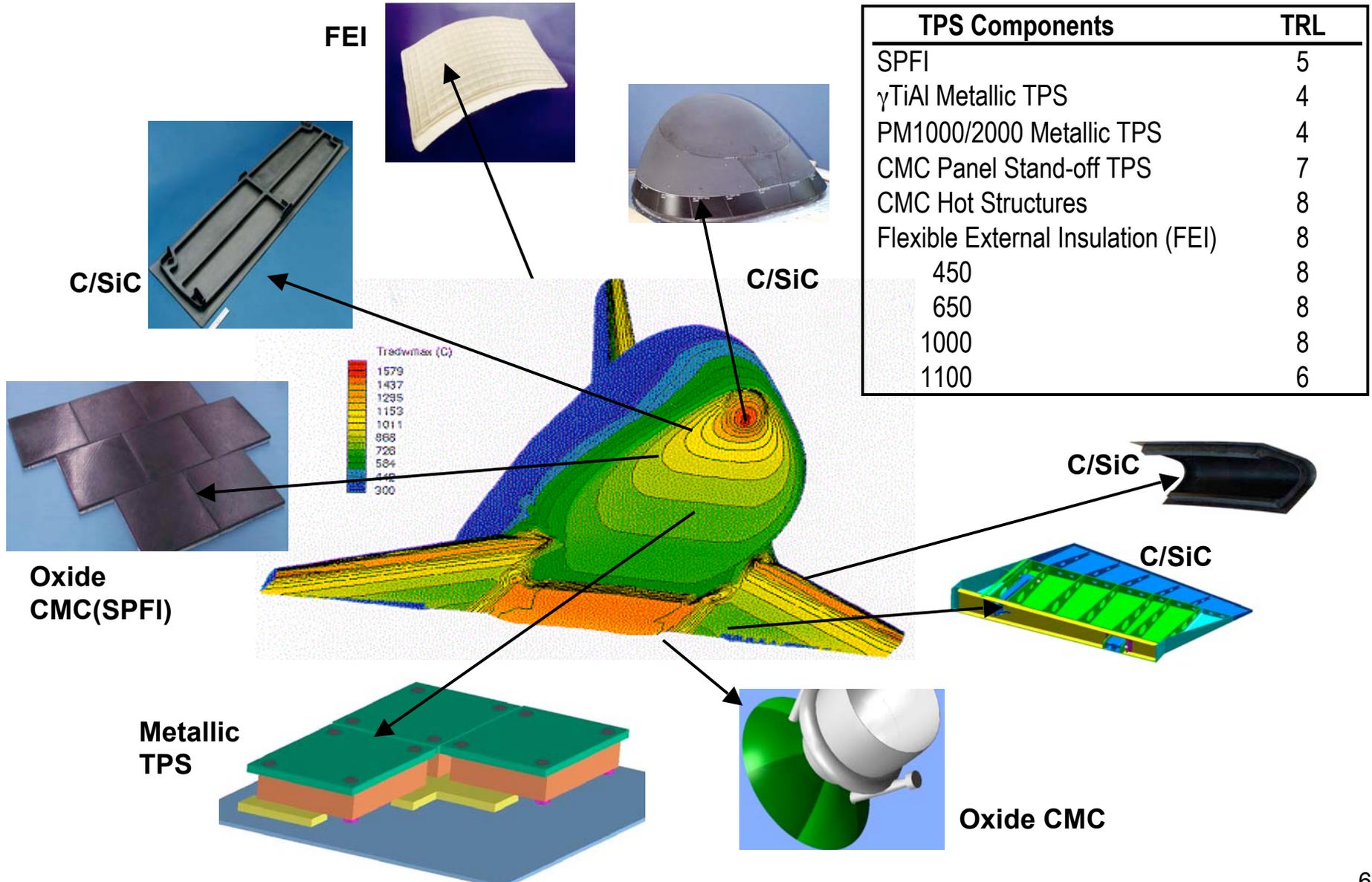
- Nosecap provided by DLR (Germany) (C-C, liquid Si infiltration fill cracks, final CVI SiC coating)
- Nose skirts (2) provided by DASA (Germany)
- Chin panel provided by MT Aerospace
- Nose assembly has undergone full qualification (qual units)
 - Vibration
 - Thermal (radiant)
 - Mechanical



- ◆ **C/SiC bodyflaps**
 - MT Aerospace

~\$20M

EADS TPS & Hot Structures Hardware for Hopper



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Intermediate Experimental Vehicle (IXV)

◆ Part of ESA FLPP

- Run by NGL Prime, joint venture of Astrium (F, D) and Finmeccanica (I)

◆ PDR end of 2007, first flight end of 2010

◆ Objectives

- System design experience for lifting reentry vehicles
- Flight test in representative environments TPS & Hot Structures for Next Generation Launchers (NGL)
- ATD data to validate tunnels and CFD

◆ Build on X-38 nose and body flap experience

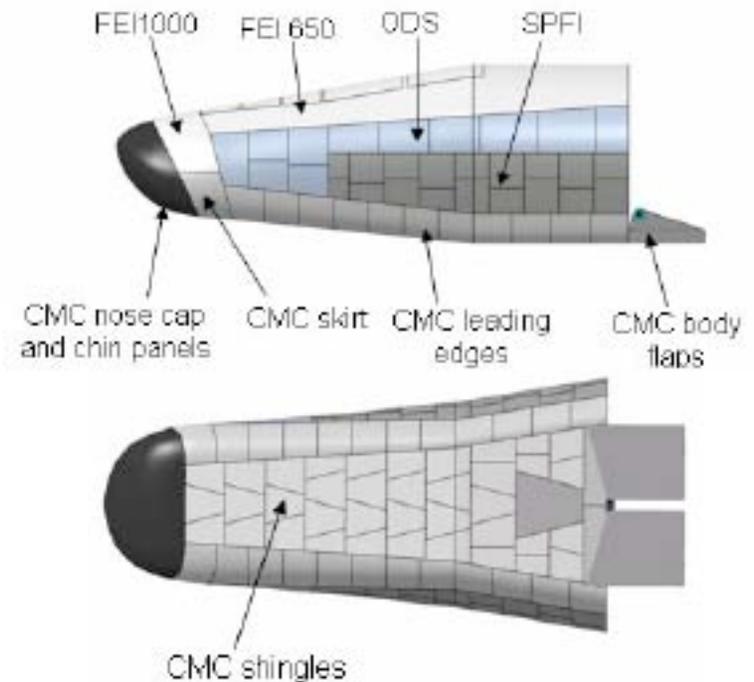
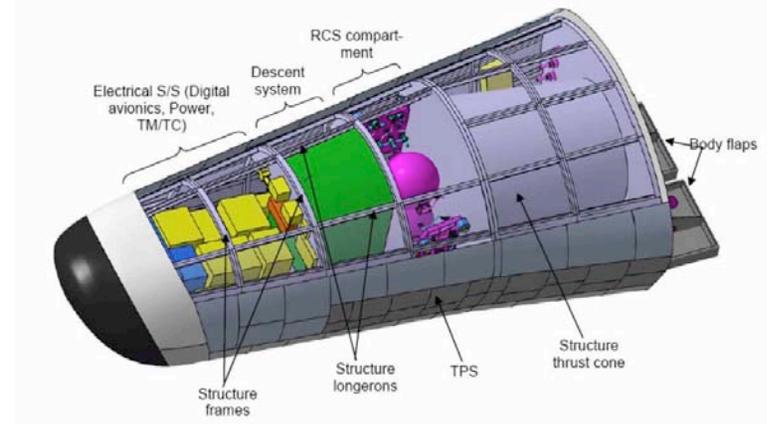
◆ Both experimental and functional

◆ Leeward and base side utilizes Flexible External Insulation (FEI)

- FEI 1000, 650,450
- ODS metallic TPS

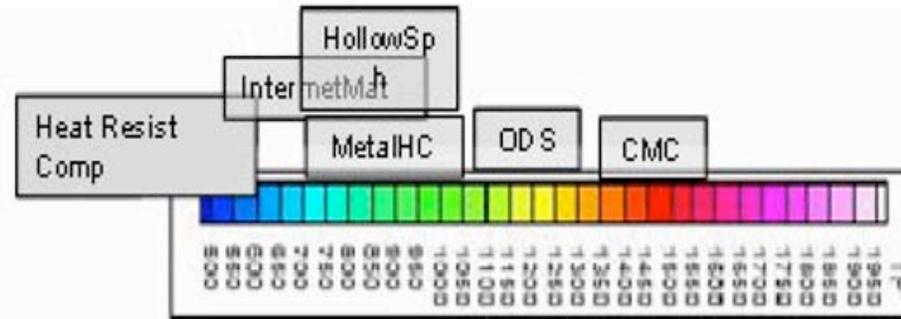
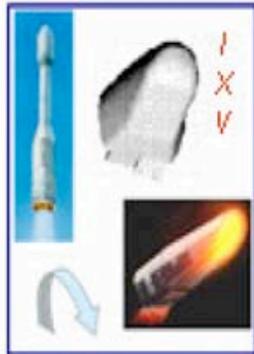
◆ Windward side

- C/SiC shingles of different size
- C/SiC leading edges, either fixed hot structure or shingle
- Surface Protected Flexible Insulation (SPFI)



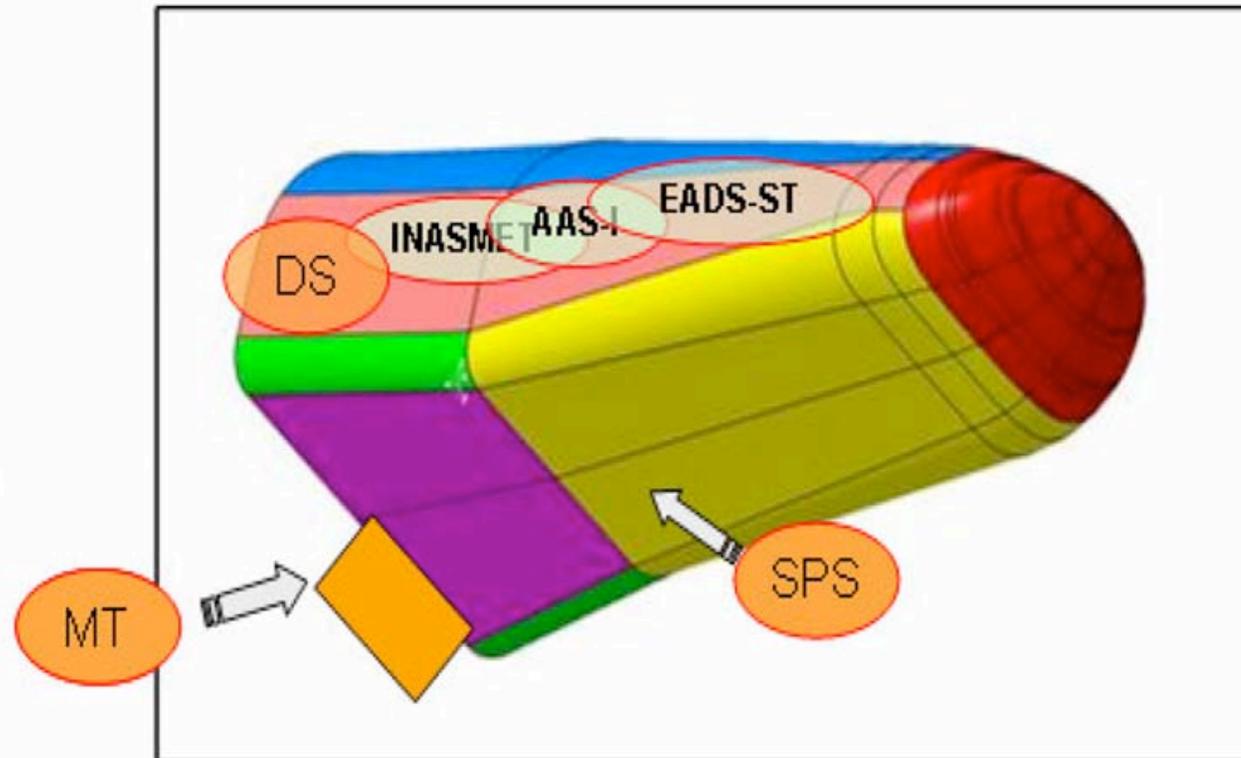
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IAC-06-C2.4.02

TPS & Hot Structures Technologies on the IXV



Technology themes: IXV application areas

- Baseline
- Flight Experiment

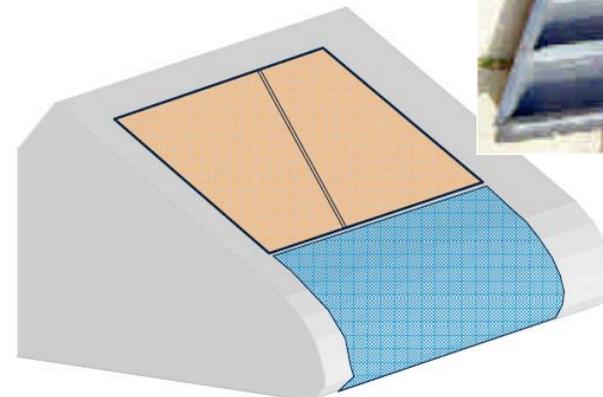
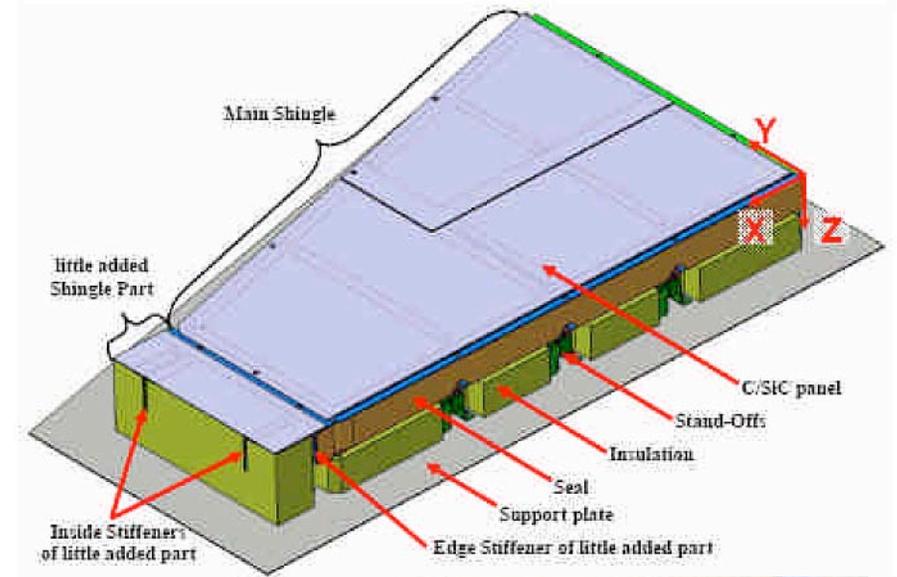


IXV C/SiC Hot Windward Surface TPS (Snecma)

◆ TRL 4-5, baseline vehicle technology

◆ Development tasks

- Base material characterization - long duration PWT tests
- Sub-assembly test (lift-off, flight, re-entry environment)
 - **Structural integrity**
 - Sine and random test of hard mounted TPS
 - 2 shingle, seals, interfaces, etc.
 - **Structure characterization**
 - Modal survey for design assumption correlation purposes
- Test demonstrator in representative thermal and pressure environment
 - **CMC TPS shingle sub-assembly**
 - **Scirocco PWT 1000 sec**
 - Structural integrity in worst thermal environment
 - Insulation performance for support structure
 - Seal integrity and performance
 - Attachment interfaces insulation and stress relief functions
 - Degradation characterization
 - Analysis models verification



IXV CMC Shingle TPS (Snecma)

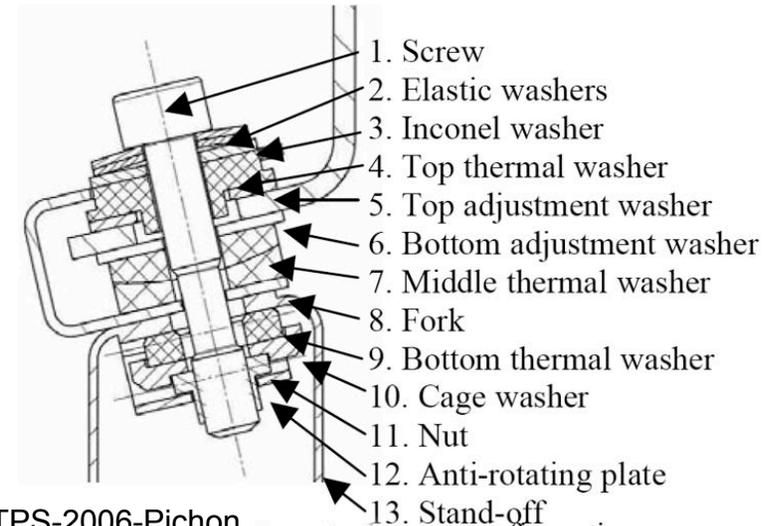
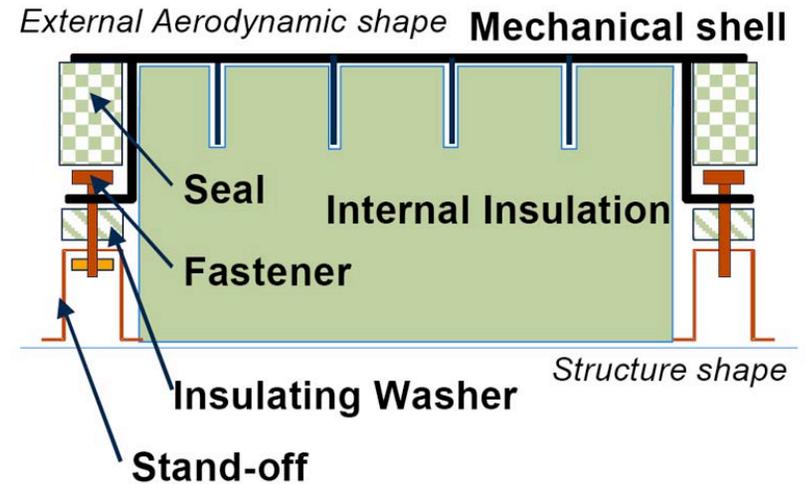
◆ Decouple the thermal (insulation) and mechanical functions

◆ Design

- External C/SiC thermal shield panel
- Outer oxidation protection system
- Internal ceramic felt insulation
- Static high temperature seals
- Special attachment fixtures combining isolation and thermal stress relief

◆ Tasks

- Design of panel and attachments
- Analytical validation of design
- Manufacturing of complete large shingle
- Mechanical test of C/SiC panel
- Testing likely done by now
 - **Dynamic**
 - **Acoustic**
 - **Thermal**
 - **Thermo-mechanical**



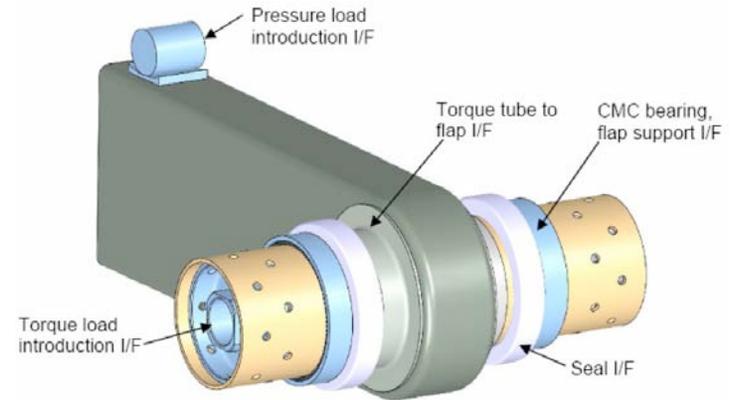
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 ESA-TPA-2006-Denaro
 AIAA-2005-3375
 AIAA-2006-7950
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IXV C/SiC Control Surfaces (MT Aerospace)

- ◆ Includes hot interface components (bearing, seals, joints)
- ◆ X-38 based design and manufacturing
- ◆ TRL 4-5, baseline vehicle technology

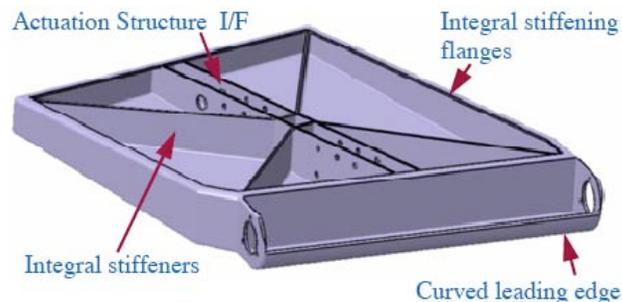
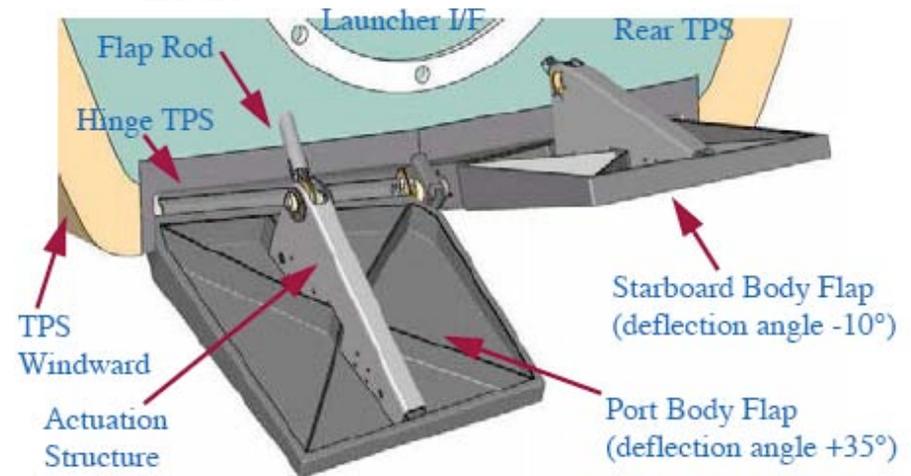
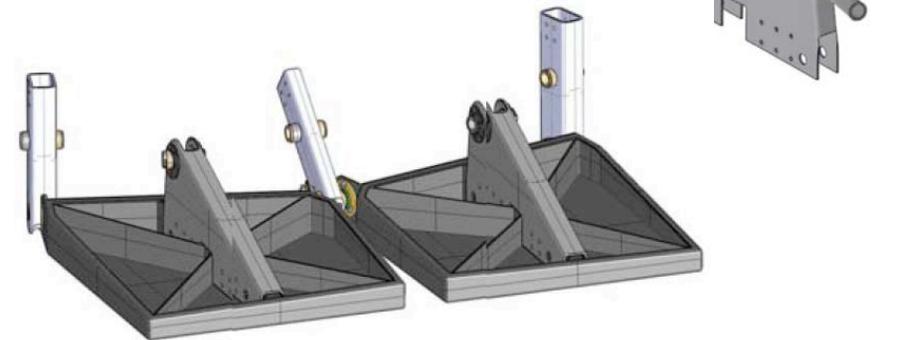
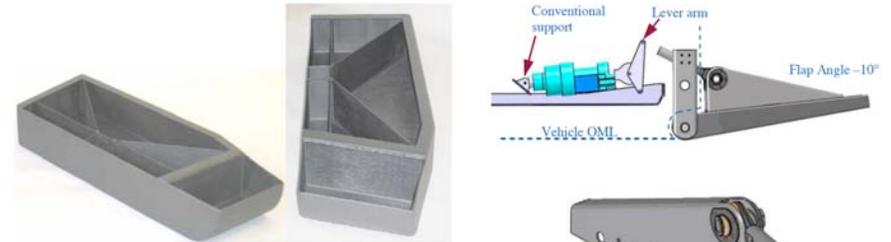
- ◆ Torque driven body flap
 - Prototype roller bearing sub-assemblies
 - Dynamic seals
 - Driving torque load introduction interface
 - Tube to flap frame joint (validating a “one shot” production process of complex composite parts)

- ◆ Development tasks
 - Hot verification of structural strength of joint (in-situ joining manufacturing technology) between torque tube and flap frame
 - Thermo-mechanical cycling of body flap demo with IXV T, P profiles
 - **Structural integrity of demo in worst thermal mechanical conditions (50 cycles)**
 - **Dynamic hot seal performance**
 - **Hybrid (metal & CMC) roller bearings functionality, integrity, and attitude maintenance**



Pre-X CMC Flap Development (MT Aerospace)

- ◆ **C/SiC design**
- ◆ **Mass is 23.63 kg (7% over goal)**
- ◆ **Flap structure**
 - Cross-wise stiffeners yields most efficient torsion stiffness (1st eigenmode)
 - 2.5 - 5 mm thick
 - Open box vs closed box for X-38 design
 - Evaluated both 1 and 2 piece
- ◆ **Ceramic bearings**
- ◆ **Attachment at hinge line**
 - Rectangular C/SiC tubes
- ◆ **Actuation mechanism**
 - C/SiC rod vs arc used on X-38
- ◆ **Hot dynamic seals**
 - Nextel/saffil
- ◆ **CMC fasteners**
 - Fewer than X-38 due to no box cover



IXV Metallic Sandwich TPS

◆ Metallic sandwich TPS

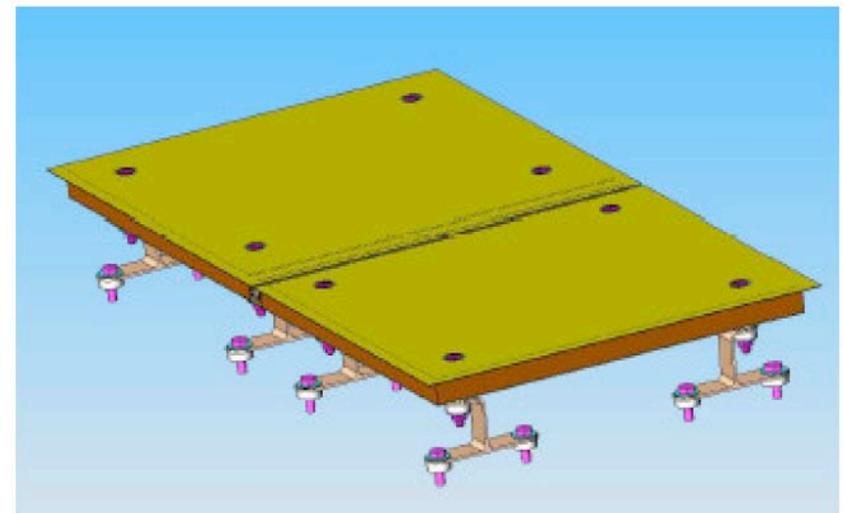
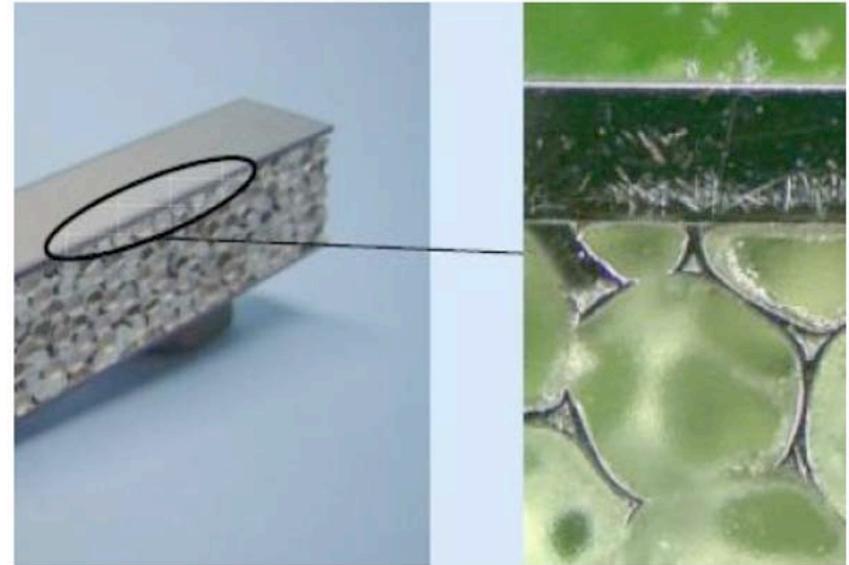
- Multiple cycles to 900°C
- Core is stainless steel hollow spheres (Alcatel Alenia Space (I) and Plansee (A))
- HollowMet core (ODS hollow sphere)

◆ TRL 2-4

◆ Passenger experiment on IXV

◆ Development tasks

- Material development and characterization for core
 - **Minimize mass for given thermal mechanical load**
- Thermal cycling of subassembly of ≥ 2 tiles, including interfaces, seals, and insulation
- Hypervelocity impacts testing (exploit energy absorption of material)



IXV Metallic Honeycomb TPS

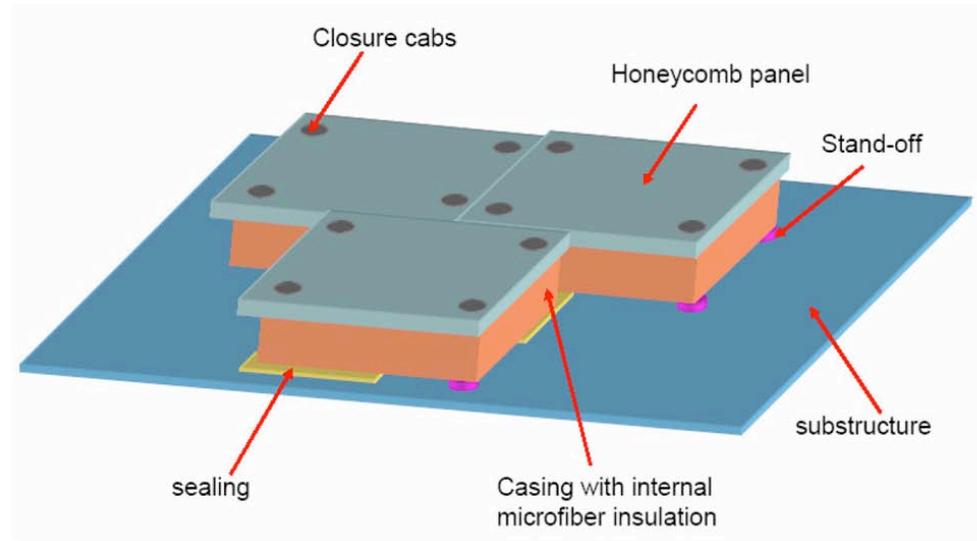
◆ TRL 2-4

◆ TIMETAL 1000 for use to 850°C (Astrium)

- Orthorhombic TiAl (Ti_2AlNb) or TiAl reinforced TiB
- Passenger experiment on IXV

◆ ODS Superalloys up to 1250°C (Dutch Space)

- IN 617
- Baseline vehicle technology
- Windward aft or leeward aft
- Development tasks
 - Design trades on seals, insulation, and interfaces to cold structure
 - Manufacture and test of selected design
 - Thermal cycling under IXV thermal and pressure profiles (2 TPS tiles)
 - Foils production
 - Core manufacturing
 - External sheet to core brazing



TIMETAL panels

IXV Metallic TPS & Hot Structures (Dutch Space)

- ◆ **AEOLUS team since 1993, lead by Dutch Space**
- ◆ **X-38 hot rudder**
 - Fab and tested a PM-1000 rudder to 1200°C (1 yr)
 - Requirements changed
 - Qualified Ti/CMC rudder (1 yr)
- ◆ **Sandwich panel**
 - PM-1000 facesheets
 - PM-2000 core
 - Vacuum brazing
 - 47 ascent/descent cycles - good condition
 - Low and high speed (hail, 208 m/sec) impact test performed - good performance
- ◆ **New design (post X-38) demonstrated**
 - Thermo-mechanical tests performed and compared well to analysis
 - Sandwich panels with inserts and edge members
 - Corrugated webs with stress/strain reducing clips
- ◆ **Extensive materials database developed**
- ◆ **Manufacturing development performed**

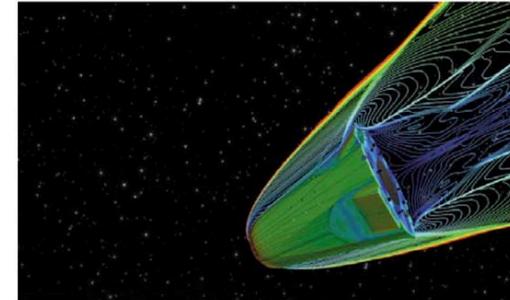


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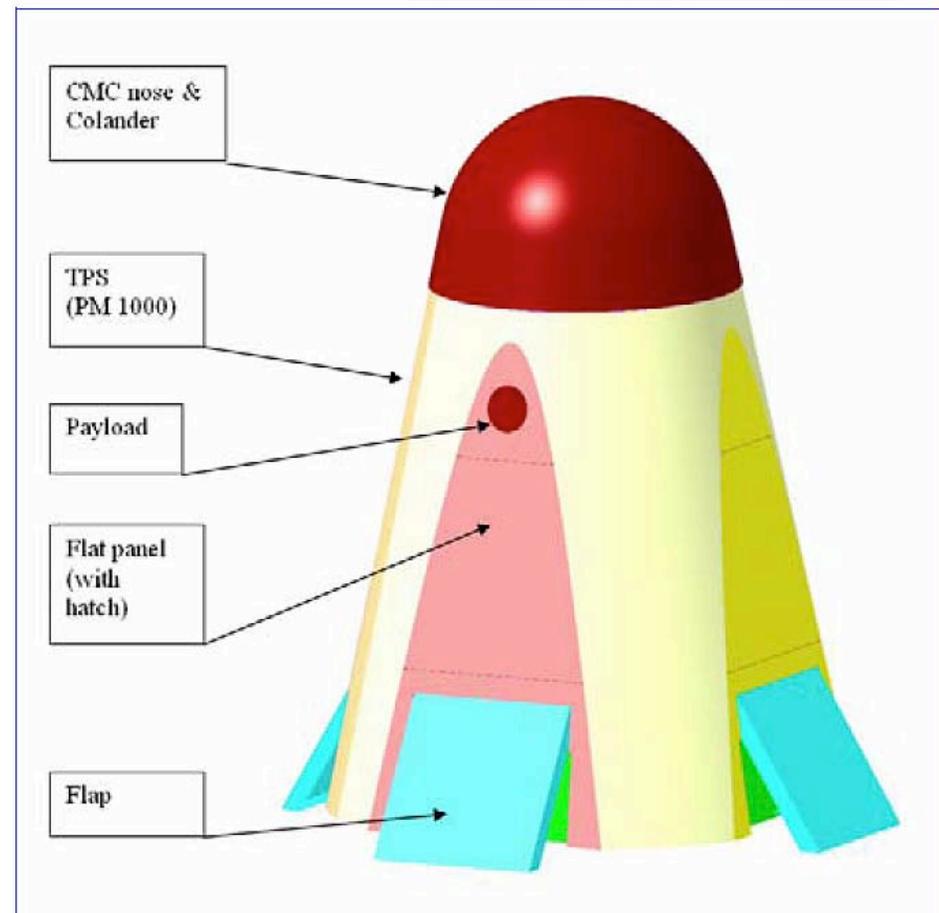


European eXPERimental Re-entry Testbed (EXPERT) Flight Experiment TPS (ESA)

Configuration: Blunt cone configuration with a pyramidal shape (called KHEOPS) having four flat surfaces, each with a fixed flap (two fixed flap settings).

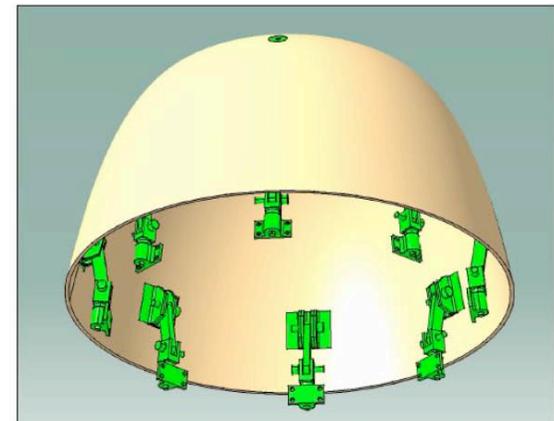
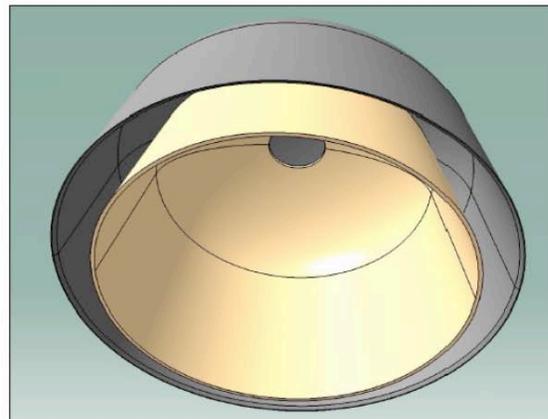
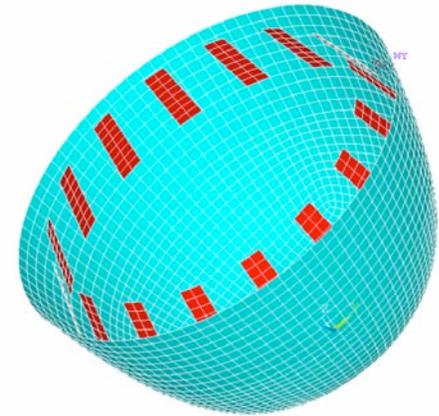


- ◆ Relatively large nose radius ($R_N < 0.4$ m, $L = 1.7$ m, $d = 1.3$ m) to minimize stagnation heating rates and ablation pollution
- ◆ 5 km/sec, entry path angle -5.5° , 3° AoA
- ◆ Curved corner TPS (4)
- ◆ Flaps---study complex physics and X-38 issues; protected with TPS, instrumented on both sides
- ◆ Flat panels, including flap box and flaps (1050 mm², 1100 mm high)



EXPERT C/SiC Nose Cap (DLR)

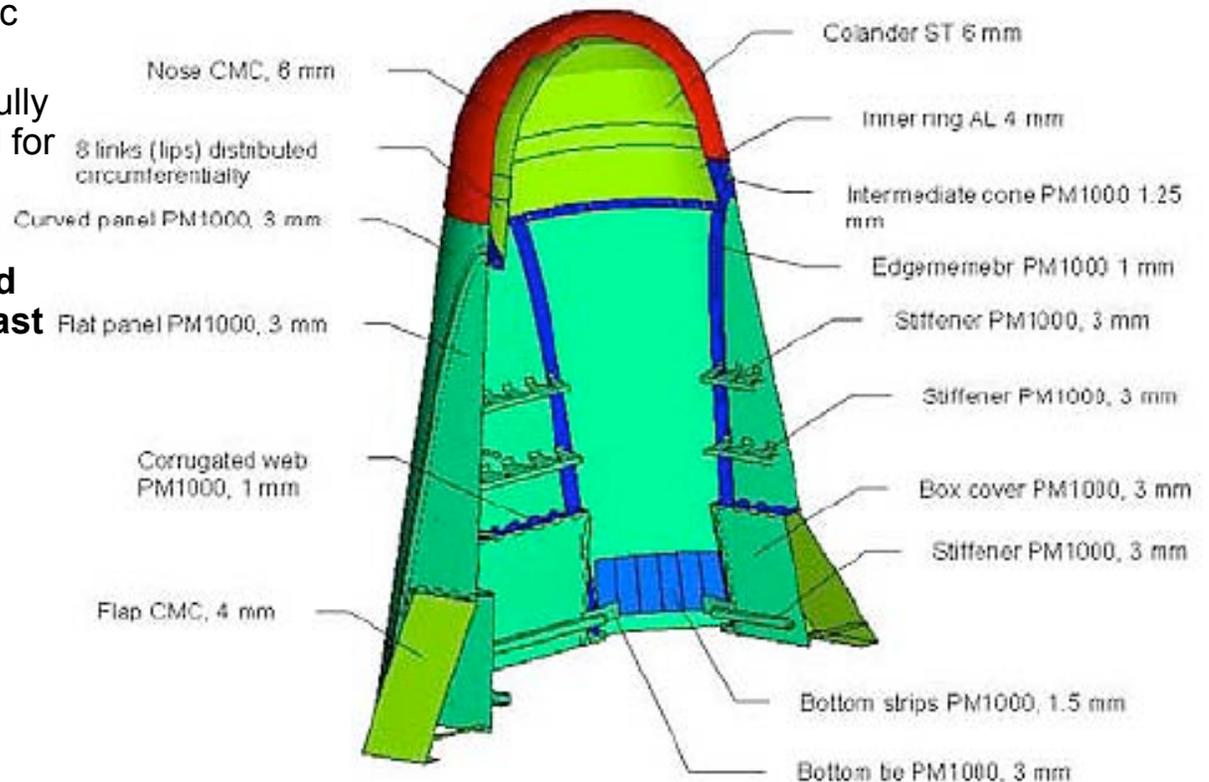
- ◆ Based on X-38 experience (led by DLR Stuttgart)
- ◆ Internal flexible insulation below surface
- ◆ $q_{\max} = 1,600 \text{ kW/m}^2$
- ◆ Material choice C/C-SiC
 - Avoided ablator
 - Geometrical stability
 - Chemical pollution of flowfield
- ◆ Load transfer from nose to vehicle cold structure
 - Elevated temperatures
 - Thermal expansion of nose
 - Thin metallic brackets bolted to nose and to cold structure
 - Less susceptible to side loads than X-38 based double bolt-joint design
 - Low complexity and cost
- ◆ Active oxidation in dissociated environments is accompanied by a sudden temperature increase of up to 500K.
- ◆ Recombination coefficients determined for C/SiC and PM 1000 in O_2 and N_2



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AIAA-2005-3309
ESA-TPS-2006-Reimer1
ESA-TSP-2006-Herdrich1

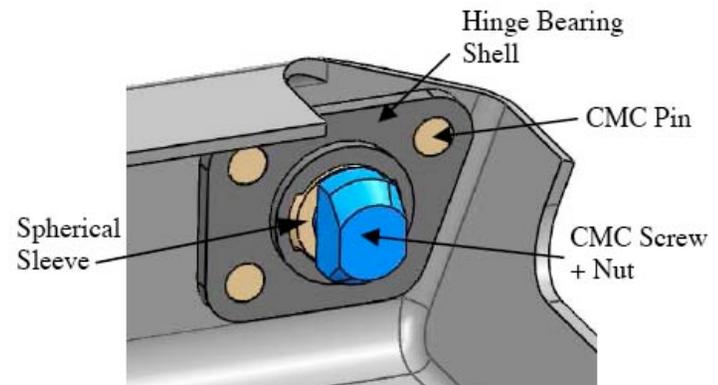
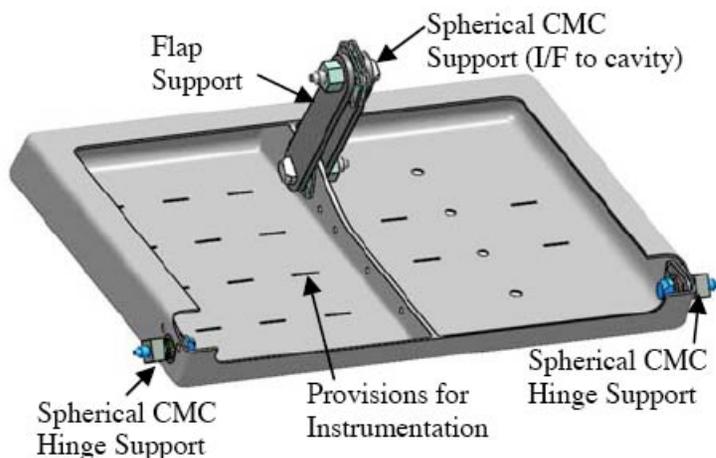
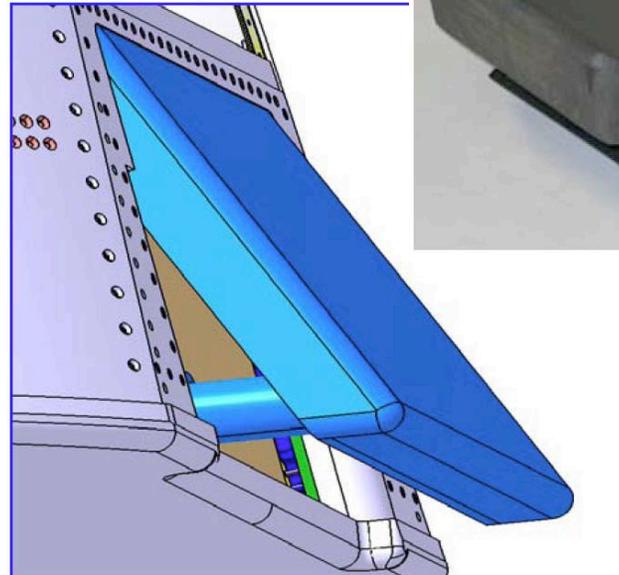
EXPERT Metallic TPS

- ◆ ODS PM 1000
- ◆ $q_{\max} = 225 \text{ kW/m}^2$
 - CFD assumed partially catalytic CMC and PM 1000
 - Nose non-catalytic, PM 1000 fully catalytic. Thus 1.2 factor used for conservatism
- ◆ Extensive FEA performed
- ◆ Mechanical stiffness to withstand re-entry dynamic pressure and fast depressurization during ascent
- ◆ Internal flexible insulation below surface
- ◆ Nose attachment to vehicle and metallic TPS
 - 4 mm step at RT, flush at max temperature
 - Seal designed to seal both hot and cold
 - Used inverted cone which is pulled upwards by expanding metallic TPS and counteracts the downward movement due to drag
 - Inverted cone designed to follow the deformation ($\sim 2\%$) of the PM 1000 metallic TPS



EXPERT CMC Open Flaps (MT Aerospace)

- ◆ Fixed at 20° deflection
- ◆ Open flap, 396 x 315 x 50 mm
- ◆ Two spherical supports at the hinge line
- ◆ Static hinge line seal
- ◆ Flap support connected to flap main body and PM 1000 cavity via spherical CMC bearings
- ◆ All joints CMC to eliminate CTE problems
- ◆ Flap box is designed as heat sink since flap is much hotter than metallic TPS capability
- ◆ Bearing shells fixed by CMC pins to flap main body
- ◆ Hinge seal fibrous saffil core wrapped in 1 layer Nextel clamped between flap leading edge and cavity



Unmanned Space Vehicle (USV)

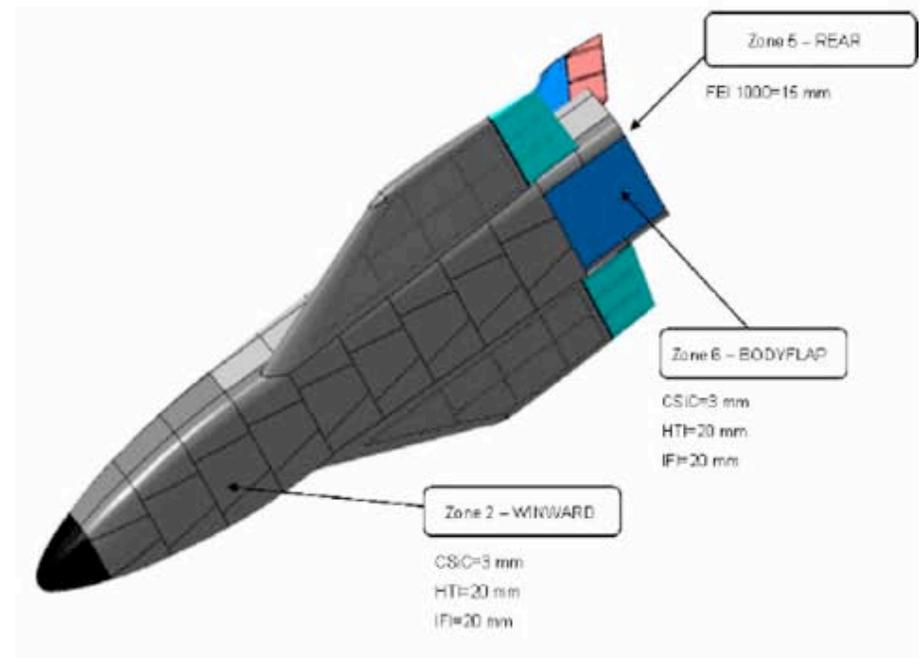
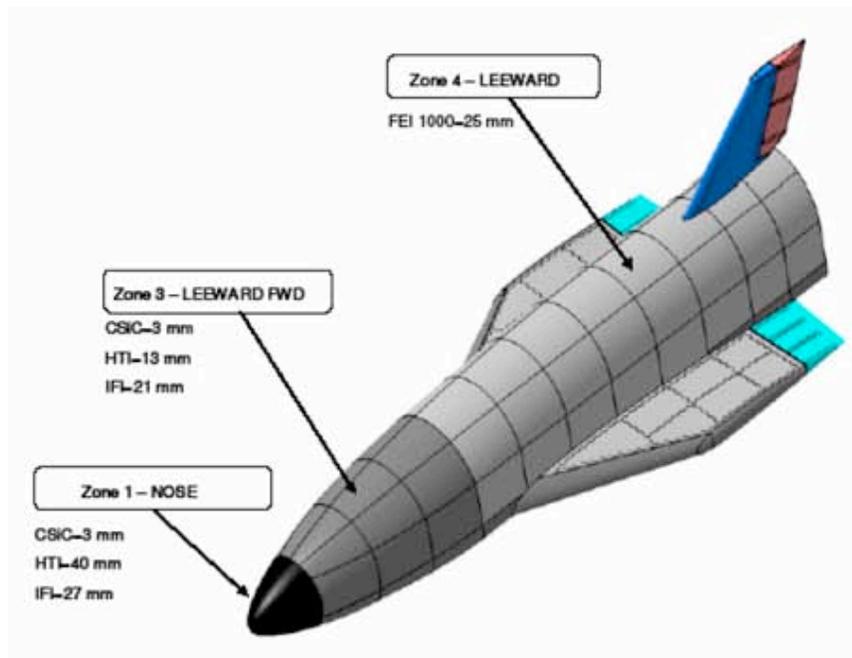
◆ Italian Space Agency / CIRA

◆ Technology development

- Sharp hot structures
 - Wing leading edges
 - Nose cap

◆ Orbital test bed: Flying Test Bed - X (FTB-X)

- Entry from LEO at 200 km
- $< 20^\circ$ AoA
- < 20 min entry



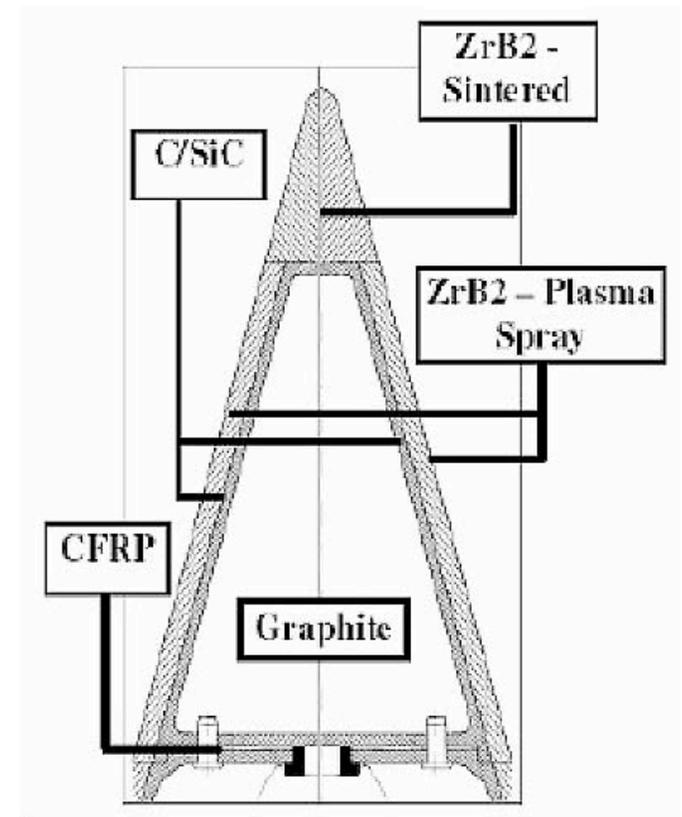
USV Ultra High Temperature Ceramics (UHTC) Nose

◆ Nose design

- Bulk graphite core
- Truncated conical C/SiC frame from PIP (Fabbricazioni Nucleari)
- ZrB₂-SiC coating on C/SiC frame by plasma spray (Centro Sviluppo Materiali)
- UHTC conical tip from hot pressing (National Research Council Institute for Ceramic Materials)

◆ UHTC primary focus area

- Core/shell configuration
 - ZrB₂ core
 - (Zr,Hf)B₂ shell
- Electrical Discharge Machining (EDM), and its effect on the surface
 - Cu, Zn contamination
 - Decreased flexure strength
- Mechanical assembly
 - Coupling pin (UHTC material to reduce thermal stress)
 - Contact pressure not important
 - Compressive stresses key

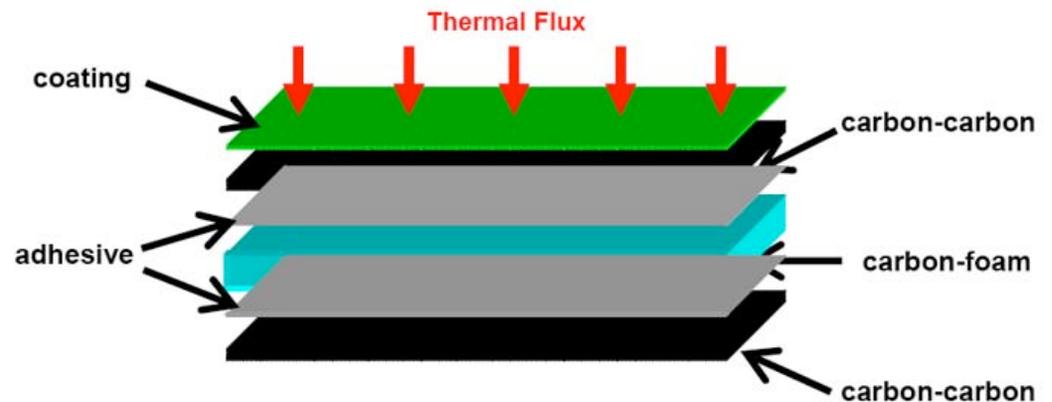
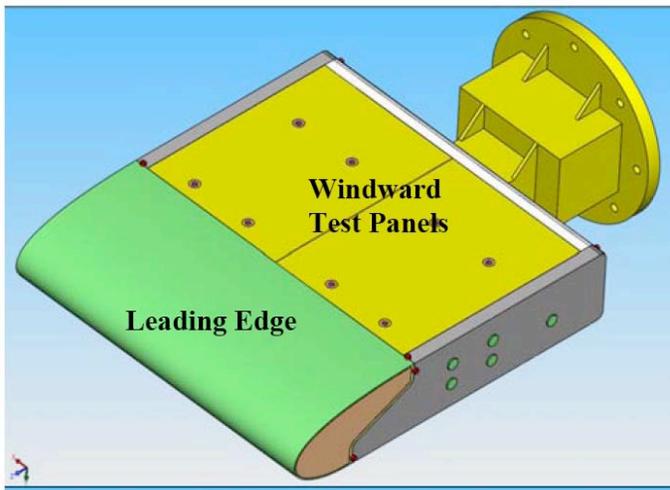
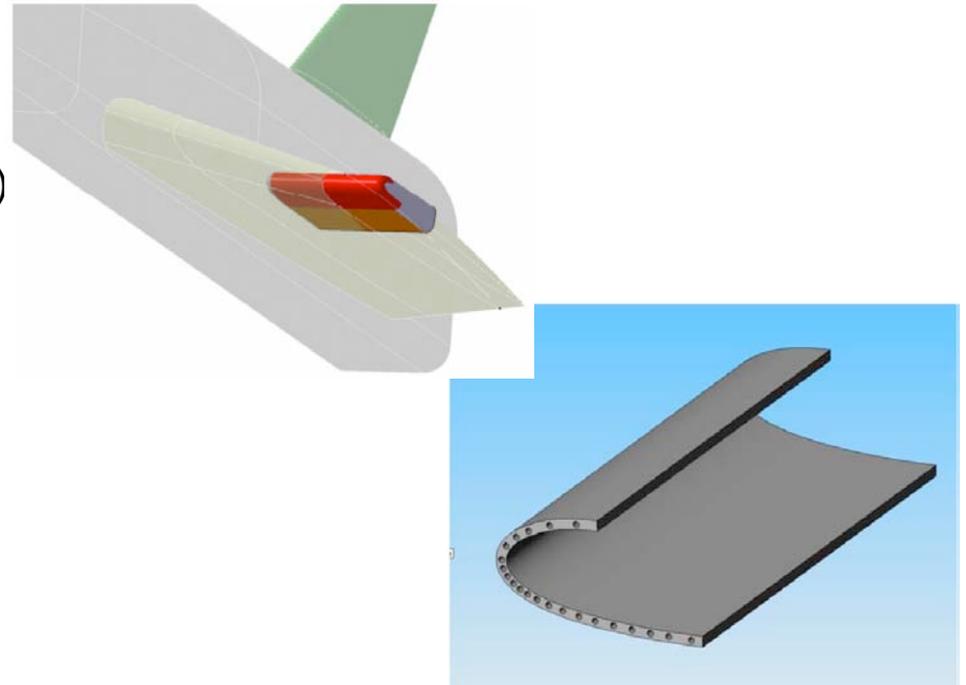


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USV Wing Leading Edge (Italy)

- ◆ **Advanced Structural Assembly (ASA)** program funded by ASI
- ◆ **Wing test article for PWT test**
 - Leading edge (interchangeable options)
 - **Actively cooled: Inconel**
 - **UHTC**
 - Hybrid sandwich panel up to 2000°C (windward surface)
 - **C/C facesheets**
 - **C foam core - evaluating both co-processing and secondary bonding**
 - Leeward surface MMC (CSM)
 - **Ni sheets and SiC/Al₂O₃ fibers**



ESA-TPS-2006-Fossati-1

USV UHTC's

◆ Multiple fabrication routes studied

- Sintering aids
- Reactive hot pressing starting from solid precursors
- Spark plasma sintering for densification
- Introduction of second phases (SiC and MoSi₂) to improve oxidation resistance and mechanical properties

◆ Complex shaped components via Electrical Discharge Machining

- Compared diamond tool machining vs EDM on ZrB₂-SiC



USV UHTC Emissivity and Catalycity

◆ Compositions

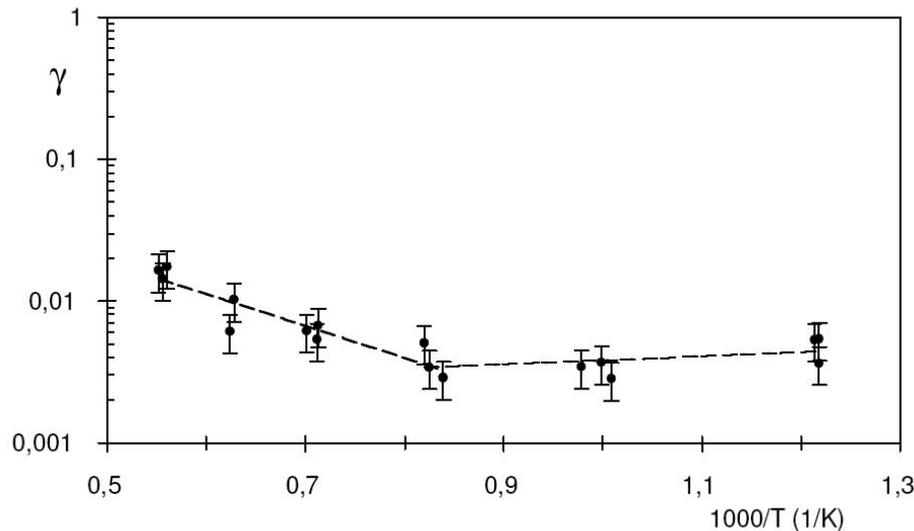
- A: ZrB₂ + SiC + sintering aid (MoSi₂)
- B: ZrB₂ + HfB₂ + SiC + sintering aid

◆ Total hemispherical emissivity 10⁻³ and 200 Pa

- A: large difference due to pressure. 200 Pa higher ϵ due to oxide layer
- B: small difference due to pressure

◆ Catalycity

- Just composition A so far

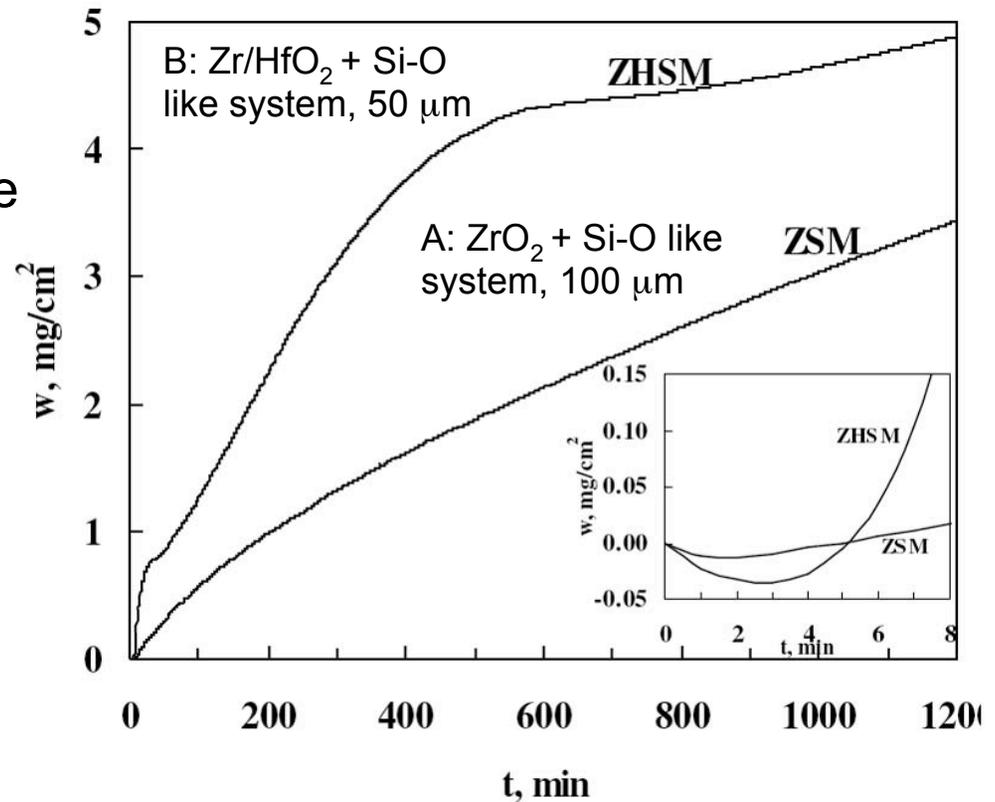


Total hemispherical ϵ ,
Composition A

200 Pa		10 ⁻³ Pa	
T (K)	ϵ^{\wedge} (T)	T (K)	ϵ^{\wedge} (T)
1037	0.77	1100	0.60
1169	0.71	1416	0.55
1250	0.72	1556	0.61
1319	0.73		
1485	0.75		
1681	0.72		

USV UHTC Oxidation

- ◆ 1200 min
- ◆ Dry, flowing air
- ◆ 1450°C
- ◆ Mass from TGA
- ◆ XRD & SEM
 - Presence of ZrO_2 and Zr/HfO_2
 - External glassy layer (Si-O-like system)
 - 100 μm for A
 - 50 μm for B



Sharp Edge Flight Experiment (SHEFEX)

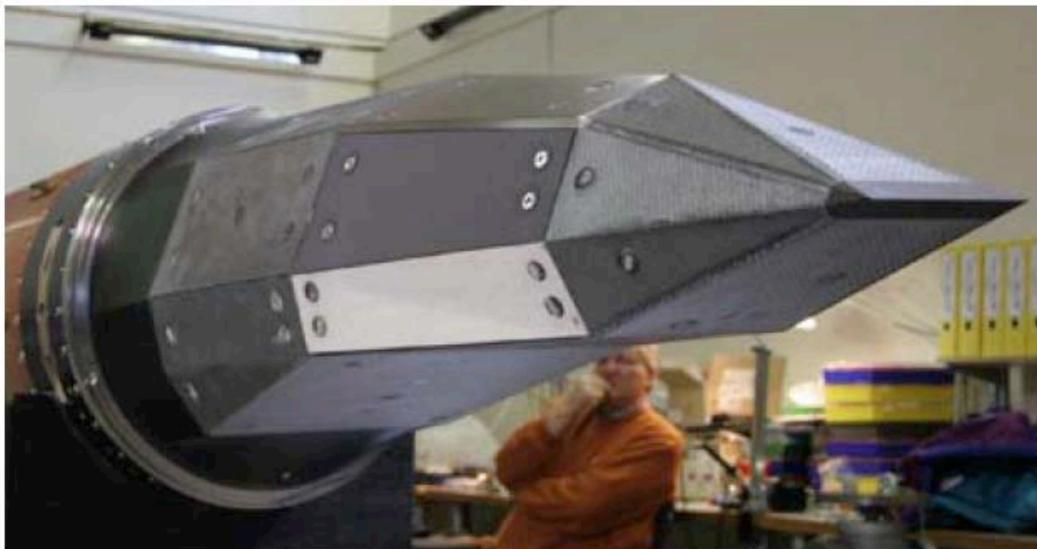
◆ Funded by DLR

◆ Objectives

- Evaluate performance of multi-faceted leading edges
- Compare numerical data with flight results

◆ Flight Oct 27, 2006

- Mach 7 between 90-20 km
- 300 km apogee



AIAA-2003-7030
AIAA-2006-7926
AIAA-2006-8071
AIAA-2006-7921
AIAA-2006-8027



SHEFEX (DLR)

- ◆ **TPS, hot structures experiment, Oct. 2005 flight**

- Apogee 211 km
- 550 sec

- ◆ **~3 ft long, 1.5 ft diameter**

- ◆ **Test flat, faceted, panels**

- ◆ **Seals and attachments included in test**

- ◆ **Primarily CMC's with some metallic TPS**

- ◆ **CMC panels utilizing DLR's liquid silicon infiltration (LSI) process**

- Central post with flexible standoffs at the corners (thermal expansion not suppressed)
- Fibrous matt insulation under cover plate
- CMC fastener connects panel to central post.

- ◆ **C/C-SiC leading edge**

- ◆ **WHIPOX (Wound Highly Porous Oxide) seals**

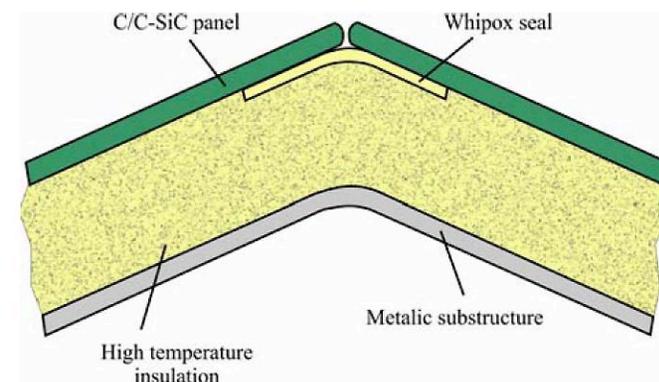
- Oxide fibers (Nextel) embedded in porous mullite or alumina matrix

- ◆ **Passenger experiments**

- 2 ceramic (EADS)
- 2 metallic (Plansee)
- Ceramic (MT Aerospace)

- ◆ **Aluminum structure**

- ◆ **All in-flight instrumentation integrated into TPS**



Sustained Hypersonic Flight Experiment (SHyFE)

- ◆ **Funded by UK Ministry of Defense**

- ◆ **Objective**

- Design and fly a prototype ramjet capable of sustained hypersonic flight

- ◆ **Vehicle**

- Weight ~ 30 kg, 1.5 m long, 7 in. dia.
- Sounding rocket boost to M 4 at 15 km, accelerate to M 6 at 32 km, cruise for 200-300 km
- Ballistic climb from M 4 to M 6 that takes ~ 60 sec.
- Diesel fuel
- Shock on lip is M 4.8

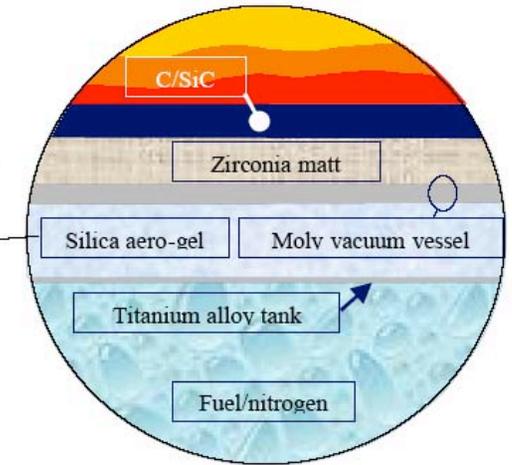
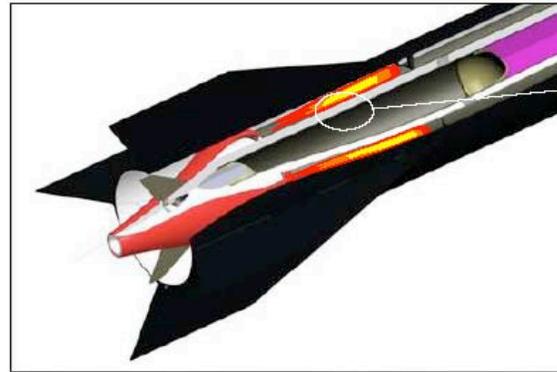
- ◆ **First flight Aug 2009, second flight 2010**

- ◆ **Thermal management**

- Minimize heat ingress from combustion chamber (2400K) to center body components

- ◆ **C/SiC used for vehicle construction**

- MT Aerospace fabrication
- Air-breathing propulsion experiment
- Practically the entire flight exp is C/SiC, except a Ti tank
 - MT Aerospace is fabricating the C/SiC via CVI
 - The fuel flows in an annulus between 2 C/SiC tubes
 - The fin roots are bonded to the body
 - MT Aerospace has eliminated a lot of the bolts by bonding and some other creative techniques that they have not discussed

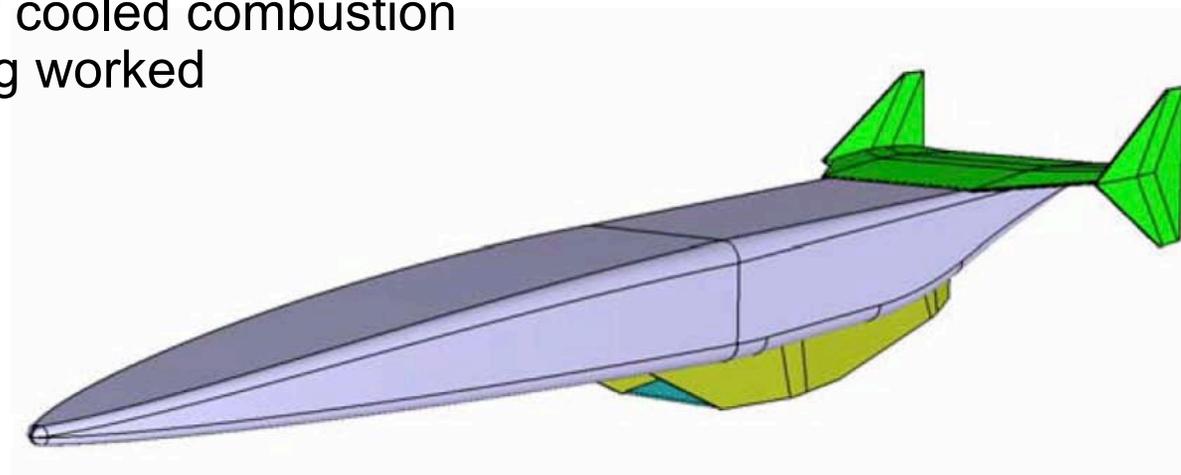


AIAA-2003-7030
AIAA-2006-7926
AIAA-2006-8071



LEA

- ◆ MBDA and Onera (France)
- ◆ 6 flight tests 2010 - 2013 in range of M 4-8
- ◆ 4.5 m long
- ◆ Not recovered
- ◆ 20-30 sec flight
- ◆ One of the key required technologies is fuel-cooled composite structures for combustion chambers
 - C/SiC actively cooled combustion chamber being worked



AIAA-2003-6918
AIAA-2005-3433
AIAA-2006-7925
AIAA-2006-8072
AIAA-2005-3434

LEA PTAH-SOCAR Actively Cooled Composites

◆ MBDA / EADS ST

◆ Duct structure

- Obtained by weaving with stitching yarns through removable mandrel
- 100 x 100 x 130 mm³
- Pin-fin coolant channel
- No machining of channels (stitched)
- Back-up structure required
- 10 kg/m², with backup structure 30% lighter than metallic cooled structure
- Utilized CVI followed LSI (liquid silicon infiltration) for rapid (days vs weeks for CVI), low-cost densification

◆ Hot test

- Cooled by air
- Tested at M 7.5 conditions
- Supersonic combustion air/H₂
- Twelve 10 sec tests

◆ Next step - larger structures

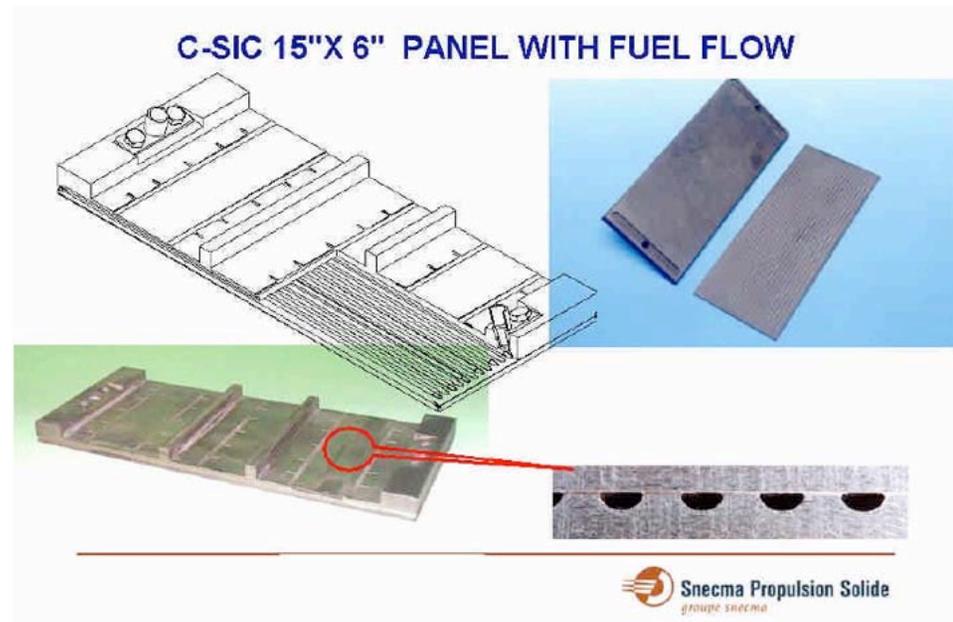
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AIAA-2005-3433

AIAA-2006-7925

AIAA-2006-8072

AIAA-2005-3434



LEA CMC Cooled Combustion Chamber

◆ Snecma and Onera (through PWR & AFRL, A3CP program)

◆ Snecma C/SiC (Sepcarbinox)

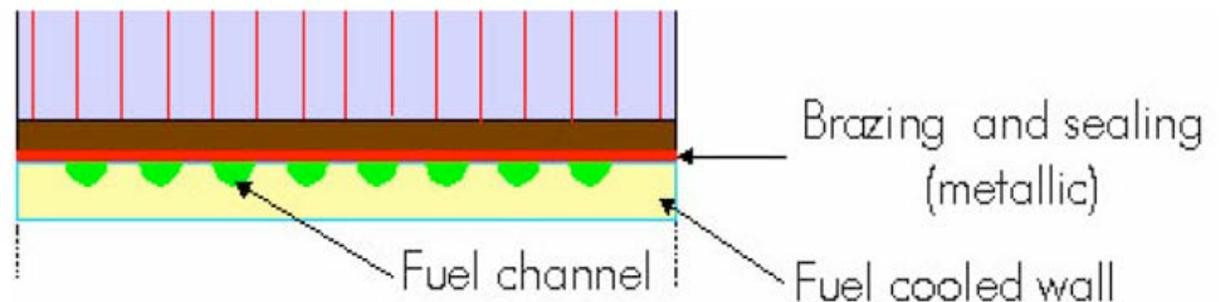
- Brazed 2 panels
- Machined grooves in the hot side panel
- Integrated manifolds on cold side
- 115 x 40 mm with 3 channels

◆ Tested at AFRL radiant facility

- JP7 fuel coolant
- 1.21 MW/m² max heat flux
- 6.9 MPa (1000 psi)
- Good correlation with analysis

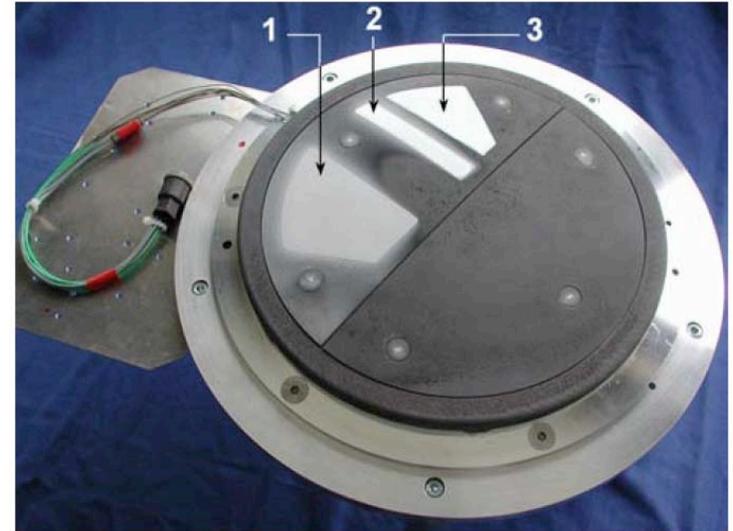
◆ Same panel tested in an Onera scramjet engine test facility

- H₂ for combustion
- Up to 1.5 MW/m²



DLR Coatings Flown on FOTON

- ◆ **FOTON is a Russian flight experiment (15 days in orbit)**
- ◆ **C/C-SiC via Liquid Silicon Infiltration (LSI)**
 - CFRP via process such as RTM
 - Pyrolysis at 900°C in Ar leads to porous C/C
 - Siliconizing at 1600°C in vacuum includes LSI and formation of SiC matrix
- ◆ **Developed yttrium silicate coating**
 - Performed well in PWT tests
 - Flew on FOTON
 - 1 and 2, CVD SiC + yttrium silicate via low pressure plasma spray
 - 3, CVD SiC + titanium oxide slurry via “painting”



FOTON and EXPERT



Agenda

◆ **Background**

- Comments on prior ESA workshop
- X-38
- Hopper

◆ **Flight Vehicle Based Technology Development**

- IXV (ESA)
- EXPERT (ESA)
- USV (Italy)
- SHEFEX (Germany)
- SHyFE (UK)
- LEA (France)
- Foton (Russia)



◆ **Non-Vehicle Specific Technology**

◆ **Concluding Remarks**

Actively Cooled CMC Thrust Chamber (DLR)

◆ C/C used for inner material, porosity 13-22%

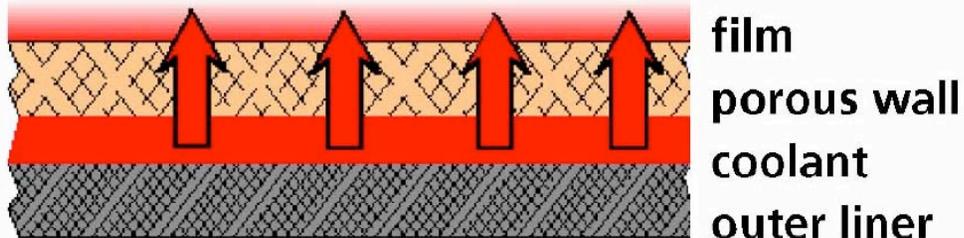
- 0°/90° lay-up
- 10 mm thick
- Temperature gradients 1000°C/mm due to low k (1-1.2 W/mK)
- 30 mm chamber diameter

◆ CFRP jacket

- Internal pressure loads
- Longitudinal compression loads due to attachments and thrust
- 5 mm thick
- Searching for H₂ barrier

◆ Permeability of multiple CMC's measured

◆ Numerous hot tests performed



Multi-Layer Insulation (MT Aerospace)

◆ Medium Temperature (~1000°C)

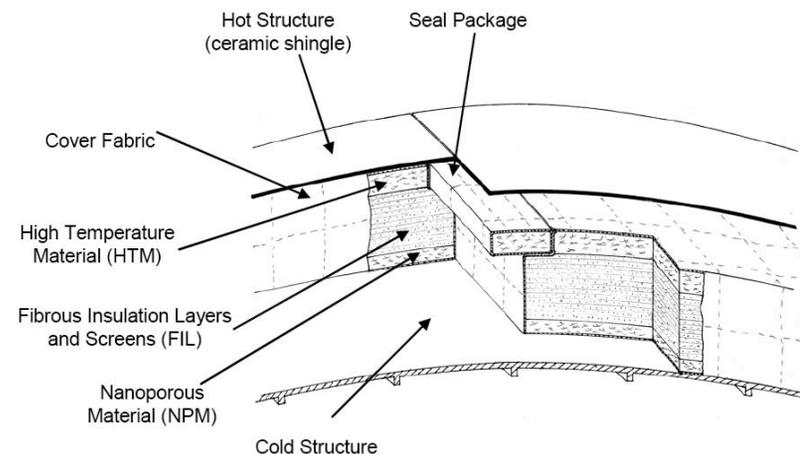
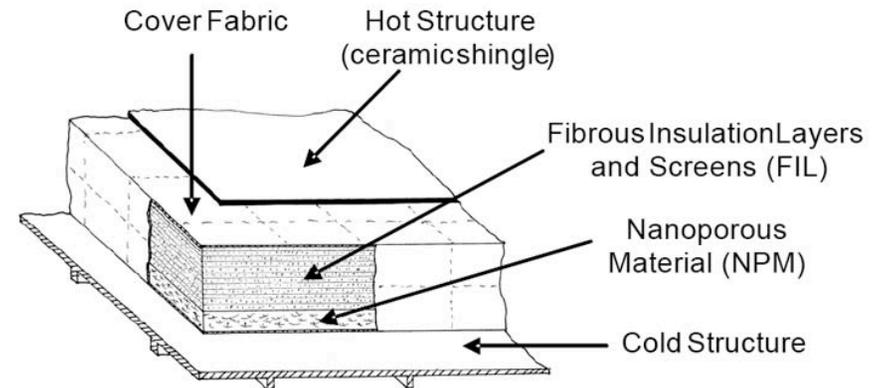
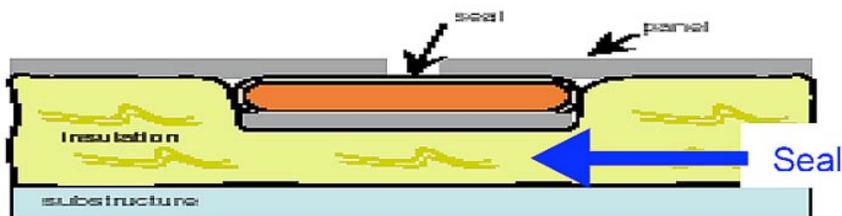
- Weight limit (by ESA) of 4 kg/m² and 40 mm thick
- Nextel 312 fabric containment
- Pryogel superior to Microtherm (density, vibration, humidity, handling)
- Consists of IMI and Pyrogel (6 mm)

◆ High Temperature (~1600°C)

- ESA limits: 80 mm, 8.5 kg/m²
- Nextel 440 fabric containment
- IMI with Zircar APA-2 for highest temperature regions and Pyrogel for lower temperature regions.

◆ Seals (DLR)

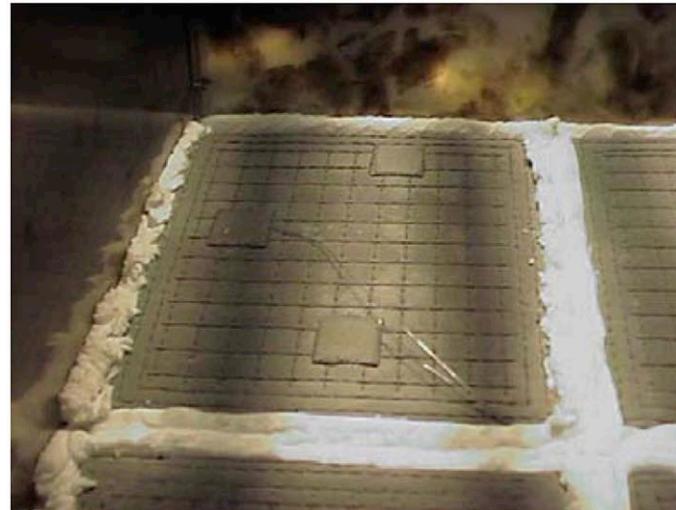
- Saffil filled Nextel 312 bag impregnated by MTMS (up to 1300K)
- Saffil filled Nextel 440 bag impregnated by MTMS (up to 1900K)
- Kept in place by C/SiC guard



Flexible External Insulation (FEI) (EADS)

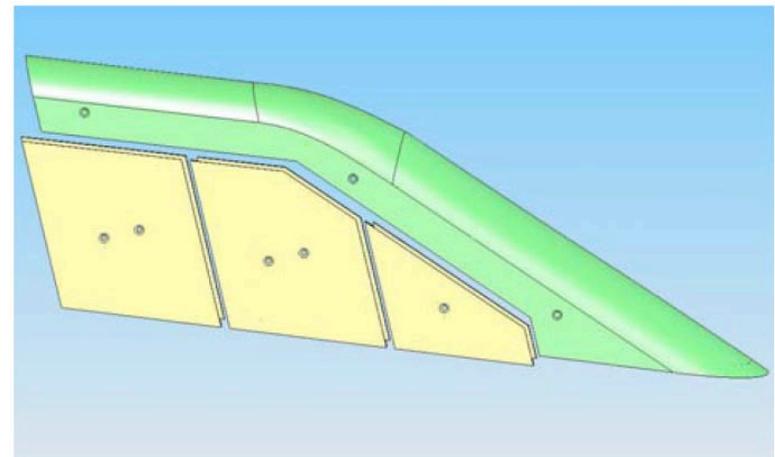
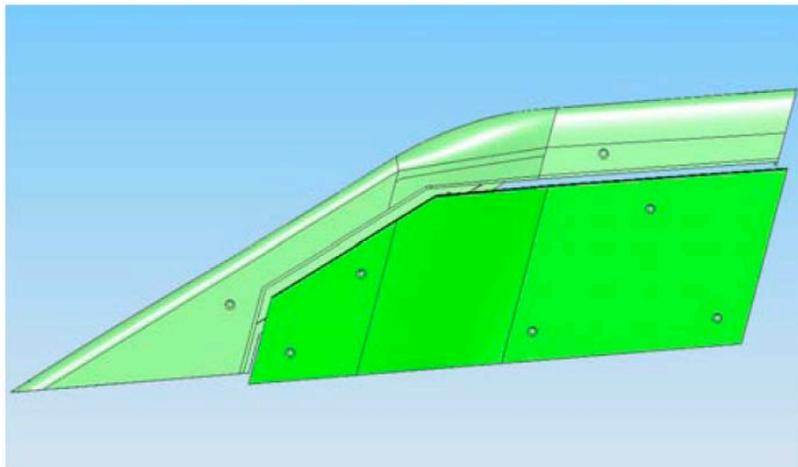
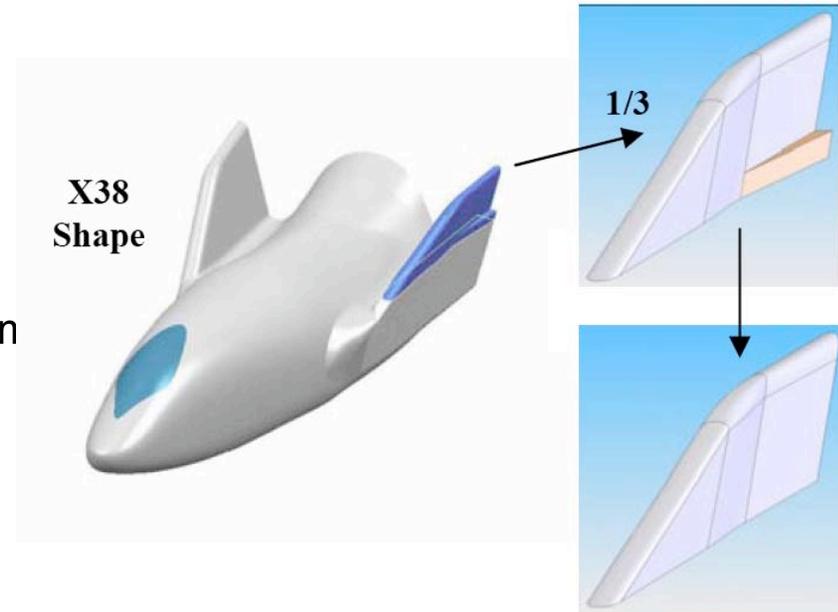
◆ Improvement of FEI blankets

- New high emittance coating developed with improved stability
- New less toxic waterproofing for initial and re- waterproofing
 - Preferred **MTES (methyl triethoxy silane)** over standard **MTMS (methyl trimethoxy silane)**
- Refurbishment and repair procedures defined
- Applied to FEI-1000 blankets and subjected to environmental testing for 10 flights.
 - **Waterproofing and coating refurbished after 4 cycles**



Hybrid Metal/CMC Winglet Hot Structure (Alenia)

- ◆ Design and analysis complete
- ◆ 1/3 size of X-38, removed hinge step
- ◆ Outboard panel and wing leading edge
 - MT Aerospace C/SiC, 3 mm thick
- ◆ Inboard panel divided into 3 panels
 - Plansee PM 2000, 1 mm thick with 2 mm thick ribs
- ◆ Seals
 - Nextel wrapped saffil
- ◆ Fabrication and PWT test planned



ULTIMATE Metallic TPS (EADS)

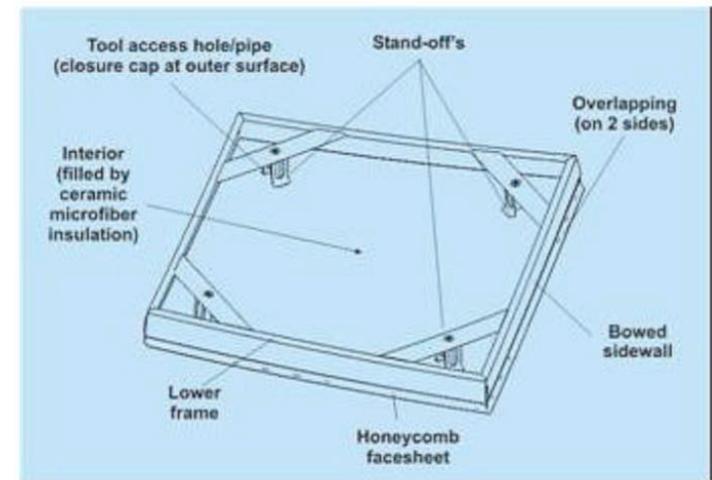
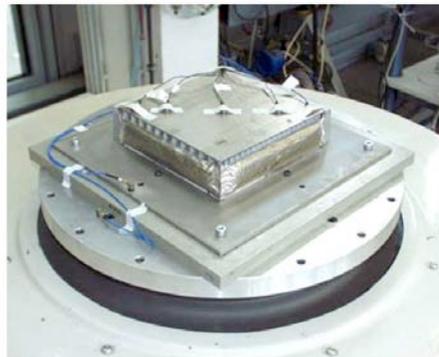
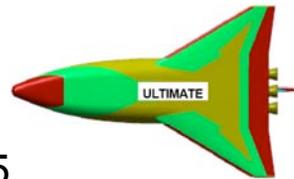
◆ EADS (Astrium)

◆ Load carrying metallic box with standoffs and internal insulation

- Outer surface honeycomb sandwich (10 mm thick, hexagonal cells)
- TiAl ?
- Omega standoffs

◆ Fabrication and test

- 200 x 200 mm (final design 500 x 5
- Single panel test
 - Vibration
 - Acoustic
 - Thermal test to ~850°C
- Assembly tests
 - Vibration
 - Thermal IR
 - PWT



ESA-TPS-2006-Fischer1

◆ SHEFEX flight

- Similar to ULTIMATE design

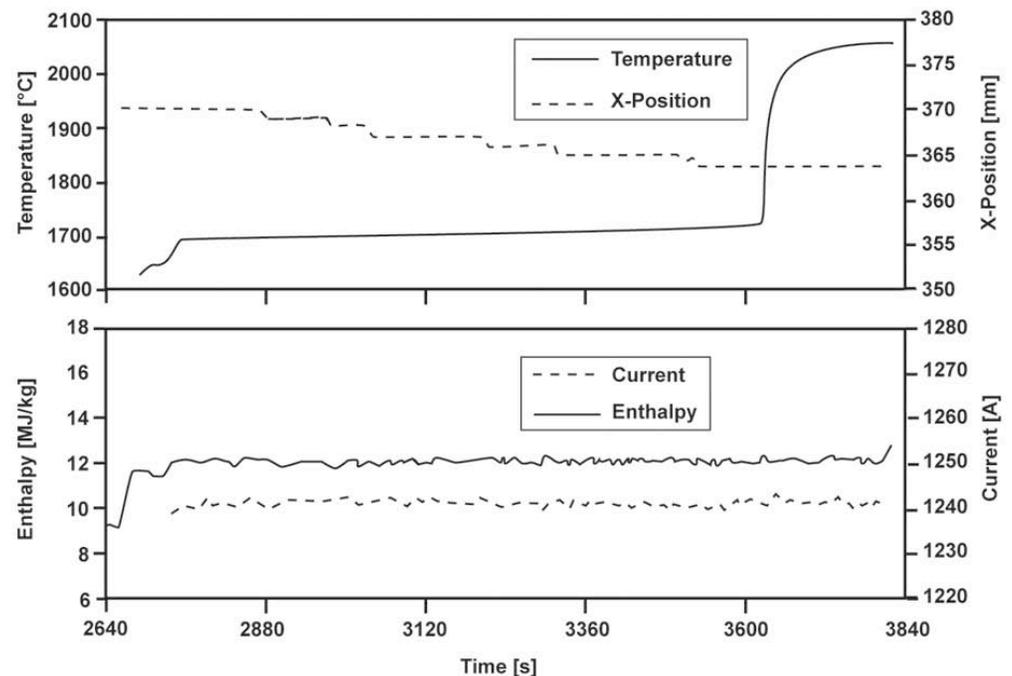
	Test Objectives	Test Conditions	Sample Definition	Number of Samples
Vibration Test	to characterise the mech. behaviour under vibrational loads	HOPPER loads	Single test panel 200x200 mm	1
Acoustic Test	to verify the mech. behaviour under acoustic loads	Re-entry vehicle spectrum	Two test panels 200x200 mm	(3)
Thermal Test	to verify the thermal behaviour under simulated reentry loads and to measure some basic thermal characteristics	IR test with $T_{max}=850^{\circ}C$ (simulated integral thermal re-entry load)	Single test panel 200x200 mm	1
Plasma Test	to verify the thermal behaviour under reentry loads and study the panel-to-panel JF and sealing	Re-entry profile with $T_{max}=850^{\circ}C$	T-gap panel cut-out max. 200x70 mm	(2)
Vibration Test	to verify the mech. behaviour of TPS assembly under vibrational loads	HOPPER loads	Array consisting of 200x200 mm panels	7
Thermal Test	to verify the thermal behaviour under simulated reentry loads and to measure global thermal characteristics (JF & sealing)	IR test with $T_{max}=850^{\circ}C$ (simulated integral thermal re-entry load)	Array consisting of 200x200 mm panels	7

Table 1: Ground Test Matrix



Passive To Active Oxidation (Germany)

- ◆ PWT tests ranging from 50 - 7000 Pa and 1650 - 1950°C with peak to 2300°C
- ◆ At steady state 1720°C/800 Pa, a small increment in energy (1 mm closer) caused a small hot spot that within 30 sec. covered the entire sample with a temperature of 2050°C
- ◆ Test very reproducible
- ◆ Also observed at 1700°C/50 Pa, 1800°C/2000 Pa, 1840°C/3500 Pa, 1940°C/7000 Pa
- ◆ Temperature jump occurring at passive to active transition
- ◆ What causes temperature rise?
 - Test done with nitrogen plasma and little oxygen (few Pa)
 - 1460°C/690 Pa temperature rose to 1850°C with little erosion
 - Strong evidence of nitrogen recombination during active oxidation
 - Half energy released during active oxidation from oxidative reactions, half from nitrogen recombination



Agenda

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- USV (Italy)
- SHEFEX (Germany)
- SHyFE (UK)
- LEA (France)
- Foton (Russia)

◆ Non-Vehicle Specific Technology



◆ Concluding Remarks

Key TPS & Hot Structures Players in Europe

- ◆ **MT Aerospace - CVI C/SiC hot structures fabrication and design**
- ◆ **Plansee - High temperature metal (Ti, superalloy, and refractory metals) fabrication**
- ◆ **DLR - LSI C/C-SiC hot structures and general hot structures design**
- ◆ **Snecma - CVI C/SiC acreage TPS fabrication and design**
- ◆ **Dutch Space - metallic TPS and hot structures fabrication and design**
- ◆ **EADS/Astrium - complete portfolio of acreage TPS, TPS and hot structures design**
- ◆ **IABG - Hot structures testing**
- ◆ **ESTEC - ESA's "field center"**
- ◆ **CIRA - Italy's Aerospace R&D Center, world's largest PWT**

Observations

- ◆ **Strong emphasis on CMC and metallic acreage TPS**
 - Europe considers CMC shingle TPS a higher TRL than metallic TPS. In the US, we have the opposite view.
- ◆ **In general, companies have niche technologies and little competition in that area, lots of collaboration**
- ◆ **Many of the companies have both the fabrication and design expertise in the same company**
- ◆ **They seem to be focused on developing technology for flight experiments**
- ◆ **They understand that flight experiments sometimes fail and move on**
- ◆ **Europeans are doing a lot of good work. Get papers and follow their progress**